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ANALYSIS OF P-WAVE RESIDUALS AND SUMMARY OF CURRENT RESEARCH

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Brief summaries of work currently underway or completed during the period from 1 October 1977 to 31 December 1977 are given in four topic areas: Source Studies, Data Analysis, Surface Wave Studies and Body Wave Studies.

Also included in the report is a detailed description of a research project not previously reported. This study is entitled, "Worldwide Observations of P-Wave Travel-Time Residuals." A

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20. ABSTRACT (continued)

large set of residuals compiled from ISC bulletins by Georges Poupinet of Institute de physique du Globe were compared with other data for the United States. The conclusions are that; (1) large negative residuals correlate with low heat flow and positive magnitude bias, and (2) large positive residuals correlate with high heat flow and negative magnitude bias. The same correlation between heat flow and travel-time residuals holds for stations located on the Russian and Siberian Platforms in the U.S.S.R.

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I. INTRODUCTION AND SUMMARY

1.1 BACKGROUND

The objective of our research program is to examine the parameters that affect the seismic signals from underground explosions. Attention is primarily directed to those features of the seismic waveforms that reliably indicate the explosion yield. Current research includes empirical studies of the available data, time signal analysis, experimental studies using small charges to simulate explosions and the development and application of theoretical and numerical methods. Emphasis is on the last of these. In particular, we are applying techniques for theoretically simulating the far-field signals from simple and complex seismic sources.

This report summarizes the work done during the fifth three-month period of the current contract.

1.2 SUMMARY OF RESEARCH DURING THIS QUARTER

Our work during this quarter has included research in a number of areas. Research projects currently underway or completed during the quarter are briefly summarized below.

Source Studies

A. Analysis of Small-Scale Explosions in Grout

A series of small-scale experiments involving 0.25 gram charges in grout cylinders were conducted last year. The experimental data is in three classes: free-field (charge far from a free surface), contained (charge at containment depth) and cratering. Computer simulations of these calculations have been completed and were quite successful in matching

the experimental results. A formal report describing these results is nearly complete.

B. Implications of the Experimental Results

A surprising aspect of the experimental data was the presence of a large, long period negative pulse arriving shortly after pP in the contained experiments. This pulse was even more noticeable in the cratering experiments when pP is essentially absent. This negative pulse had previously been noticed by Dr. J. Trulio of Applied Theory, Incorporated, in two-dimensional calculations of 150 Kt nuclear explosions at contained and cratering depths (presented at several ARPA meetings during 1977) and dubbed a "super pP." Our computational results, which matched the experimental data, also included this pulse. The origin of the pulse was poorly understood and various explanations were put forth. Assuming the negative pulse propagates like the direct P wave, Bache and Rodi (1977) explored some of the implications for teleseismic body waves and, particularly, m_b-log yield relations.

Dr. Steven M. Day of S^3 recently advanced the hypothesis that the negative pulse was actually due to near-field effects that attenuate rapidly at increasing distances from the event. A finite difference elastic calculation done by Dr. Day confirmed that the large negative pulse was present in purely elastic theories. Subsequent analytical calculations by Dr. Terrance G. Barker confirmed the identification of the negative pulse as an elastic, near-field phenomenon. Therefore, it has no signficance for far-field body and surface waves.

This experience highlights the importance of using exact theories for analytically continuing (propagating) near-field waveforms to the far-field. Theories involving ad hoc approximations can lead to serious misconceptions.

C. Representation Theorem for Analytic Continuation

We have an exact method for analytic continuation of a source in a whole-space. This has successfully been used for a number of applications (e.g., Bache, et al., 1976; Cherry, et al., 1976). For a source in a halfspace, a comparable theory has not been available and we have relied on some ad hoc approxmations in the past (e.g., Bache, Masso and Mason, 1977; Bache and Rodi, 1977).

We have recently begun to implement an exact halfspace analytic continuation theory in a computationally convenient form. The theory is based on a field representation given by de Hoop (1958).

Data Analysis

A. Decomposition of Multiple Explosions

A final draft of a topical report "Identification of Individual Events in a Multiple Explosion from Teleseismic Short Period Body Wave Recordings," by D. G. Lambert and T. C. Bache was submitted this quarter. The report was updated from the initial draft (submitted last quarter) to include a comparison of our results with the actual explosion configuration. There turned out to be six events in the array. We identified the time and amplitude of the first four with quite small error. The last two were the smallest in the sequence and could not be identified.

B. Development of Station Transfer Function

The objective of this work is to design and test a method for deriving station transfer functions for the stations of the AEDS network. If a good estimate of the signal apart from local station effects were available, such

station transfer functions could be derived by deconvolving this estimate with recorded seismograms. There are a number of ways to derive the basic pulse. Our previous work has given considerable confidence in our ability to compute synthetic seismograms to match the data apart from what appear to be station effects. Alternatively, one could select seismograms from stations where the local site effects seem very small and deconvolve with these.

The method presented here could be viewed as an improvement on the second alternative listed above. If we have a number of seismograms for stations where local site effects seem small, we can average these and further suppress what station effects are present. The averaging method is called "log spectral averaging" and is related to methods used to isolate the source wavelet in exploration geophysics.

We studied the application of our method to three presumed explosions at the U.S.S.R. Degelen test site and recorded at the stations of the AEDS network. A stable estimate of the "average source" was obtained for each where "stable" means the answer was about the same whether the average was done with the best three or best six stations. This pulse was then deconvolved with the recorded seismograms to obtain three independent estimates of the station transfer function at all stations. After filtering by a "typical" source wavelet to highlight the important characteristics, the three estimates for the transfer functions turn out to be nearly the same. We conclude that our method works for stations in a limited source region. The dependence on range and azimuth to the source remain to be investigated.

C. Analysis of Travel-Time Residuals

This work is summarized in Section 1.3 and described in detail in Section II.

Surface Wave Studies

A. Crustal Structures for NTS-ALQ and NTS-TUC

Using Rayleigh wave recordings of NTS explosions at Albuquerque and Tucson, crustal models were inverted for the NTS-ALQ and NTS-TUC paths. The results were described in our previous quarterly report (Bache and Rodi, 1977) and a Journal article recently submitted to VSC for clearance. Using these crustal structures, the surface wave amplitude-yield relations can be studied with considerable confidence that path effects are properly accounted for. This study is currently in progress.

B. Analysis of Surface Waves from the French Explosions at the Hoggar Test Site

The techniques described in the previous paragraph are being applied to recordings of the French explosions at the Hoggar test site. Good estimates for the crustal structure of North Africa are being obtained. These structures will then be used to explain some anomalies in the observations of the French explosions.

C. Analysis of Surface Waves from Siberian Explosions Recorded at TAT and CTA.

In a two-month period in 1977 there were four events in the U.S.S.R. that were almost in a direct line with the SRO stations at Taipai, Taiwan and Charters Towers, Australia. The surface wave recordings of these events are not very good

(low signal/noise) but we are now analyzing them for group and phase dispersion. If good esitmates for these quantities can be obtained, we will be able to invert for crustal structure along a long path in Siberia and across China.

D. Study of Lg

Some theoretical studies regarding the nature of the seismic phase Lg were initiated this quarter. Some initial results were presented at an ARPA meeting in Dallas, Texas January 11 to 12, 1978.

Body Wave Studies

A set of HNME recordings of eleven Pahute Mesa explosions are being carefully analyzed using synthetic seismogram methods. The objective is to isolate the different effects contributing to m_b-log yield and M_s-log yield relationships.

1.3 SUMMARY OF SECTION II: "WORLDWIDE OBSERVATIONS OF P-WAVE TRAVEL-TIME RESIDUALS"

A very large data base consisting of P-wave travel time residuals compiled from bulletins of the International Seismic Centre (ISC) were obtained from Georges Poupinet of the Institute de physique du Globe, Paris, France. Comparison of these data with other information for the United States indicate the following; (1) large negative travel-time residuals correlate with low values of heat flow and positive magnitude bias, high m_b estimates, for stations in the aseismic regions of central and eastern United States, (2) large positive residuals correlate with high heat flow and negative magnitude bias as in the Basin and Range Province of the western United States. This same correlation

between heat flow and travel-time residuals holds for stations located on the Russian and Siberian Platforms withn the U.S.S.R.

II. WORLDWIDE OBSERVATIONS OF P-WAVE TRAVEL-TIME RESIDUALS

2.1 INTRODUCTION

A very large data base consisting of P-wave travel-time residuals compiled from bulletins of the International Seismological Centre (ISC) were obtained from Georges Poupinet of the Institute de physique du Globe, Paris, France. The main intent of this report is to present these data so that they may be more generally available and to compare them with data from other studies of both travel-time residuals and body-wave magnitude bias.

2.2 DESCRIPTION OF DATA BASE

The data set consists of mean P-wave travel-time residuals observed at 524 globally distributed seismograph stations. For each station the mean residual is based on observed and calculated travel times for worldwide major ($M > 5.0$) earthquakes reported in the ISC bulletins during the years 1964 to 1970. The number of earthquakes, or individual residuals, that were used to calculate the mean station residuals and their standard errors are also part of the data set. The number of earthquakes used for the different stations is highly variable, ranging from a low of 41 for the station CED located in Cedar Springs, California, to a high of 742 for COL located at College, Alaska.

The abbreviated write-up that accompanied the tabulated residual data did not indicate whether any source or path corrections had been applied (e.g., the ISC routinely uses the Jeffrey-Bullen travel time tables for hypocentral locations which results in a dependence of the residuals

on epicentral distance). Thus, in order to determine how the residual values were arrived at, we selected one of the 524 stations for which a relatively small number of earthquakes had been used to determine the reported mean residual. The station selected is BIO, located at Biorka, Alaska. Poupinet's data sheets indicated that 45 earthquakes had been included in the determination of the mean residual at BIO. The ISC bulletins for the years 1964 to 1970 were searched for reports of residuals from all major earthquakes. The results of this search are given in Table 1.

TABLE 1

COMPARISON OF TRAVEL TIME RESIDUALS

Station	Location	Lat. (N)	Long. (W)	Poupinet $\bar{R}$	Poupinet n	Poupinet $\sigma/\sqrt{n}$	This Study $\bar{R}$	This Study n	This Study $\sigma/\sqrt{n}$
BIO	Biorka, Alaska	56° 51' 06"	135° 33' 30"	.97	45	.16	.96	45	.16

Based on the agreement between the mean residuals and standard errors ($\sigma/\sqrt{n}$) in Table 1, we conclude that the 524 residual values tabulated by Poupinet are straight averages with no corrections for source or path effects. The data appear to be restricted to event-station epicentral distances greater than 10 degrees and ISC reported residuals within three standard deviations of the mean values. In the case of BIO, 33 of the 45 earthquakes are located along the western portion of the circum-Pacific from the Aleutians ($\Delta \sim 26°$) proceeding counter-clockwise to the Fiji-Tonga-Kermadec region ($\Delta \sim 90°$).

Any attempt to apply corrections to Poupinet's data for source and path biases would require a massive effort.

In lieu of that we will compare his residual data with results from the study by Cleary and Hales (1966) to see if the lack of corrections prevents us from using these data to make inferences about regional attenuation and magnitude bias. In Table 1 we compare mean travel-time residuals determined at a set of common stations in the United States and U.S.S.R. by Cleary and Hales (1966) and Poupinet.

In general the agreement between the two data sets in Table 2 is quite good. Considering the U. S. stations, when more than ten observations are available the mean residuals obtained by Cleary and Hales (1966) agree in most cases within the standard error with Poupinet's results. On the other hand, when there are less than ten observations available the mean residuals from these two studies in many cases differ by more than the standard errors, with sign reversals in two cases (GSC and RCD). We conclude from this comparison that the large number of observations included in Poupinet's results to some extent negates source and path biases.

2.3 RELATIONSHIP BETWEEN TRAVEL-TIME RESIDUALS AND HEAT FLOW

In their study of the worldwide behavior of P-wave travel-time residuals, Cleary and Hales (1966) pointed out the correlation between residuals and heat flow. They noted that, in general, negative residuals and low heat flow values (Lee and Uyeda, 1965) are typical of shield regions; e.g., the Canadian, Fennoscandian, Asian, Indian, Australian and Antarctic shields. On the other hand, positive residuals and higher than normal heat flow are typical of continental areas which have been uplifted since the late Tertiary; e.g., regions in the vicinity of the U. S. Cordillera, Caucusus, Dinarics, Carpathians and the

TABLE 2

COMPARISON OF RESIDUAL DATA

U. S. Stations

		Cleary and Hales			Poupinet		
Station Code	Region	Number of Observations	$\overline{R}$	Standard Error	Number of Observations	$\overline{R}$	Standard Error
AAM	Michigan	6	-0.30	0.22	179	-0.27	0.10
ALQ	New Mexico	21	+0.26	0.15	449	+0.30	0.03
BKS	California	17	+0.26	0.16	592	+0.57	0.03
BLA	Virginia	13	-0.48	0.17	154	-0.22	0.07
BLO	Indiana	17	-1.02	0.16	59	-1.02	0.15
BMO	Oregon	13	-0.22	0.17	587	-0.08	0.03
COR	Oregon	15	+0.73	0.17	176	+1.04	0.07
CPO	Tennessee	6	-1.11	0.22	340	-0.81	0.05
DBQ	Iowa	15	-0.54	0.17	146	-0.92	0.09
DUG	Utah	11	+0.16	0.18	506	+0.40	0.03
FLO	Missouri	14	-0.95	0.17	177	-0.93	0.07
GEO	Washington, D.C.	12	-0.48	0.18	116	-0.23	0.11
GOL	Colorado	18	+0.24	0.16	394	+0.56	0.04
GSC	California	5	-0.64	0.23	60	+0.57	0.14
LON	Washington	10	-0.02	0.18	448	+0.05	0.04
LUB	Texas	10	-0.10	0.19	296	-0.07	0.05
MHT	Kansas	19	-0.84	0.16	147	-0.68	0.11
PAS	California	20	-0.04	0.15	589	+0.09	0.03

TABLE 2 (continued)

U. S. Stations

Station Code	Region	Cleary and Hales: Number of Observations	Cleary and Hales: $\overline{R}$	Cleary and Hales: Standard Error	Poupinet: Number of Observations	Poupinet: $\overline{R}$	Poupinet: Standard Error
RCD	South Dakota	4	-0.12	0.25	132	+0.17	0.08
ROL	Missouri	21	-0.86	0.16	76	-1.08	0.14
SCP	Pennsylvania	16	-0.20	0.16	124	-0.36	0.08
SLM	Missouri	17	-0.72	0.16	96	-0.48	0.13
TFO	Arizona	5	+0.69	0.22	550	+0.74	0.03
TUC	Arizona	6	+0.19	0.22	529	+0.31	0.04
UBO	Utah	9	+0.02	0.18	496	+0.36	0.03
WES	Massachusetts	8	-0.05	0.20	208	0.00	0.08
WMO	Oklahoma	22	-0.87	0.15	300	-0.52	0.06
	U.S.S.R. Stations						
APA	Apatity	6	-0.9	0.3	397	-0.92	0.05
ASH	Turksmen	3	+0.6	0.3	297	+0.49	0.07
BOD	Bodaybo	4	-1.1	0.3	328	-0.69	0.06
ELT	Eltsovlsa	3	(-0.7)	0.6	149	-1.20	0.08
FRU	Kirgiz	7	+0.4	0.3	421	+0.38	0.04
GRS	Armenian	2	(+1.5)	0.9	384	+0.57	0.05
IRK	Irkutsk	7	-0.8	0.2	407	-0.40	0.06

TABLE 2 (continued)

U.S.S.R. Stations

Station Code	Region	Cleary and Hales: Number of Observations	Cleary and Hales: $\overline{R}$	Cleary and Hales: Standard Error	Poupinet: Number of Observations	Poupinet: $\overline{R}$	Poupinet: Standard Error
KHE	Kheis	6	-0.2	0.3	356	0.24	0.06
KHO	Khorog	4	+1.3	0.2	372	0.46	0.05
KIS	Kishineo	6	-0.2	0.4	309	-0.34	0.05
KRV	Kirovabad	3	-0.1	0.0	340	-0.08	0.05
LVV	Lvov	7	+0.4	0.2	236	+0.37	0.06
MOS	Moscow	9	-0.2	0.2	457	-0.36	0.05
PUL	Pulkovo	8	-0.4	0.1	381	-0.54	0.05
SEM	Semipalatinsk	8	-0.7	0.3	392	-0.81	0.05
SIM	Simferopol	8	0.0	0.1	380	+0.01	0.05
SVE	Sverdlovsk	8	-0.3	0.2	477	-0.63	0.04
TAS	Tashkent	9	+0.2	0.3	529	+0.02	0.04
TIF	Tiflis	7	+0.7	0.2	406	+0.79	0.05
TIK	Tiksi	3	(-0.6)	0.7	469	-1.74	0.05
UZH	Uzhgorod	4	+0.4	0.1	316	+0.30	0.05
VAN	Vannovskaya	5	-0.1	0.3	212	+0.28	0.08
VLA	Vladivostok	2	-1.0	0.1	434	-0.03	0.05
YAK	Yakutsk	3	(-1.6)	0.7	365	-0.99	0.06

Tibetan Plateau. In this subsection we will compare Poupinet's more extensive data set for North America and the U.S.S.R. with heat flow observations for these regions compiled by the World Data Center A for Solid Earth Geophysics and published in map form in 1976.

Figure 1 is a map of North America with Poupinet's mean station residuals superimposed. The familiar regional trends (Cleary and Hales, 1966) are readily apparent in this figure. Large positive residuals are predominant in the Basin and Range Province, and large negative residuals in the central United States. The pattern of negative residuals extends north into the Canadian Shield (an extension of which is buried beneath the central United States. An area of small positive residuals is located in the extreme northeastern corner of the United States (e.g., New Hampshire and Maine).

The dashed line in Figure 1, passing through the states of New Mexico, Colorado, Wyoming, Montana, Idaho and Washington, represents an approximate boundary between regions of contrasting heat flow observations as mapped by the World Data Center. To the east of this line, which closely corresponds to the Rocky Mountain Front over part of its location, the preponderance of heat flow measurements are less than 1.8 $\mu cal/cm^2$-sec. In particular, the majority of numerous observations made in the vicinity of the Great Lakes are less than 1 $\mu cal/cm^2$-sec. As noted previously, this region is also characterized by some of the largest negative travel-time residuals.

There are only three reports of heat flow measurements within the contiguous United States greater than 1.8 $\mu cal/cm^2$-sec east of the dashed line in Figure 1. These observations, included in the small dashed circle, were made in Maine and New Hampshire in the vicinity of the small positive travel-time residuals in Figure 1.

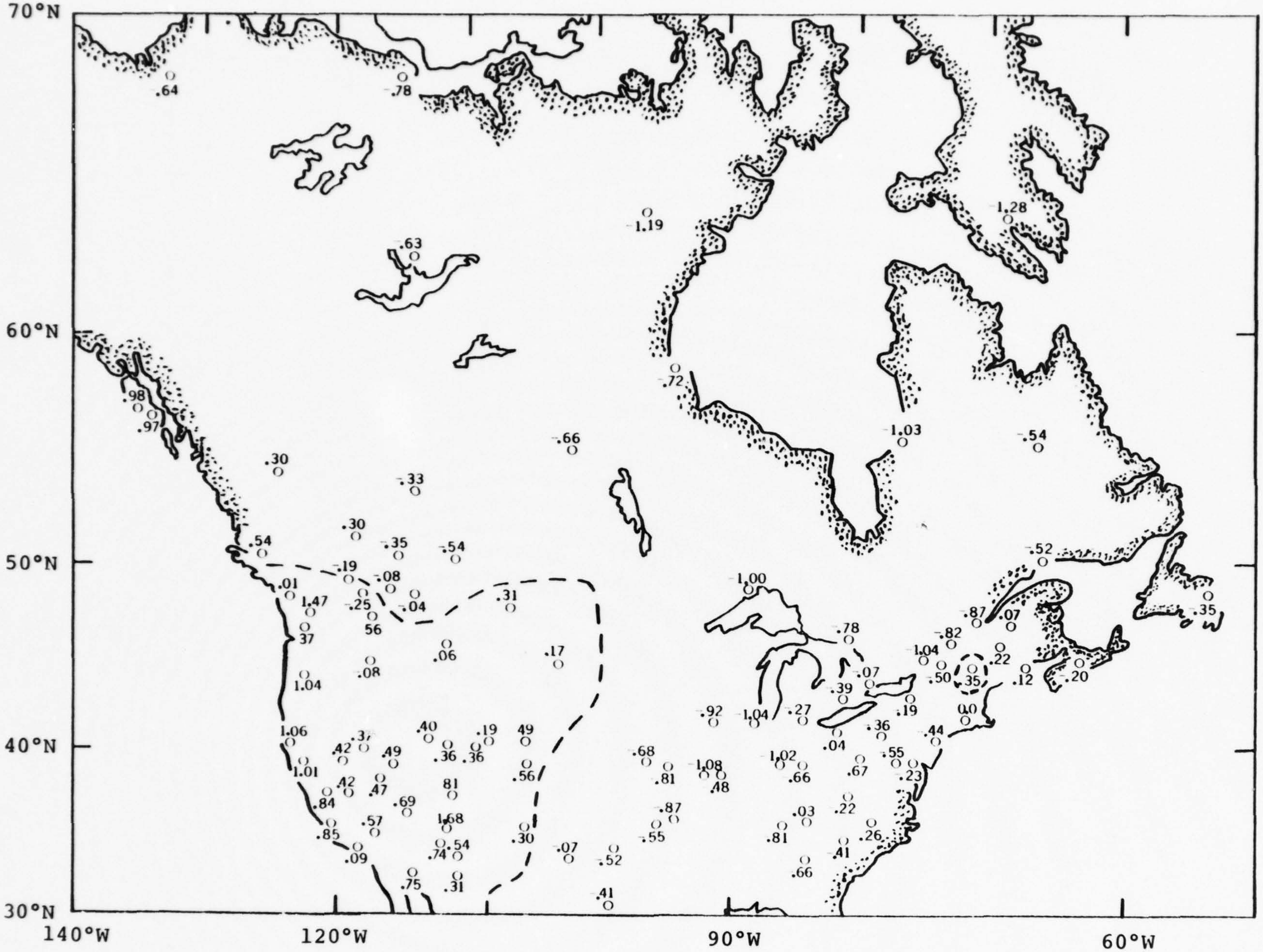

Figure 1. Map of North America with mean P-wave travel-time residuals in seconds determined at the seismograph stations indicated by the open circles.

West of the dashed line in Figure 1 there are numerous reports of heat flow values in the range 1.8 to 2.4 $\mu cal/cm^2$-sec, with the highest values reported in regions where the largest positive travel-time residuals occur. Areas of especially high heat flow and large positive residuals are located in portions of Nevada, Arizona and California.

In Figure 2 we compare Poupinet's travel-time residuals with heat flow observations for Eurasia. High heat flow and large positive residuals occur near the seismically active regions located near the bottom of this figure (Iran, Afghanistan, India, China and Japan). North of approximately 45°N latitude, the only observations of relatively high heat flow (i.e., > 1.8 $\mu cal/cm^2$-sec) are reported for the seismically active Lake Baikal, a presumed rift like feature. All measurements made on the vast Russian and Siberian Platforms have values less than 1.8 $\mu cal/cm^2$-sec. Seismic stations located on these two Platforms are consistently characterized by fairly large negative travel-time residuals.

2.4 COMPARISON OF RESIDUAL DATA WITH MAGNITUDE BIAS

In a recent study North (1977) analyzed some 400,000 station m_b values as reported in the ISC bulletins for global variations in station magnitude bias. The magnitude bias is defined as the mean difference between a station m_b and the average m_b of a large network of stations. Several criteria were applied to the data: (1) station m_b reports in the distance range 21 to 100 degrees, (2) events with three or more station m_b reports, and (3) stations which reported more than 200 events in any one year during the period 1963 to 1974. These selection criteria resulted in 72 globally distributed stations available for analysis. No magnitude data were available from stations within the U.S.S.R.

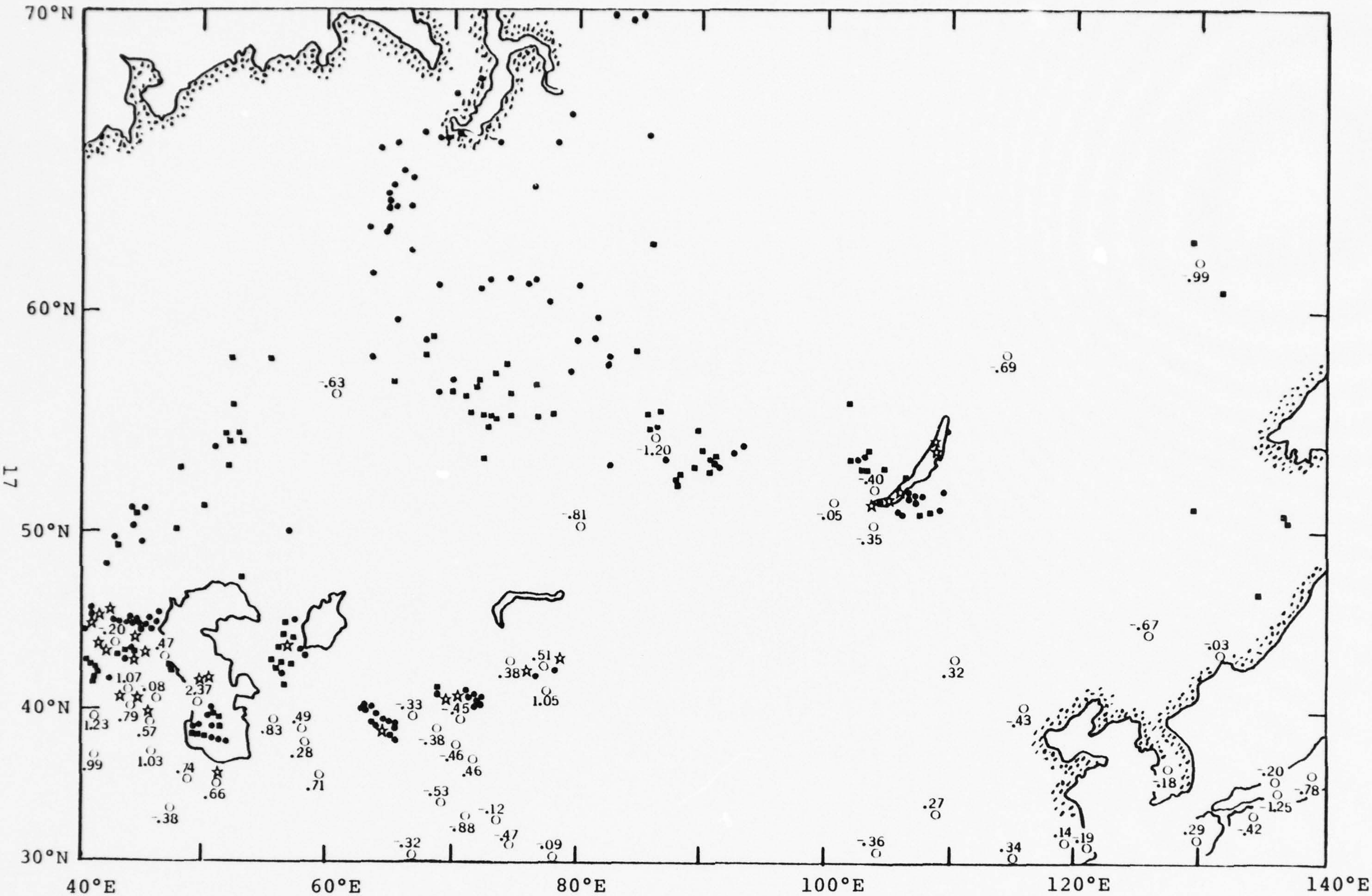

Figure 2. Map of Eurasia with mean P-wave travel-time residuals and locations of heat flow measurements. The open circles correspond to the locations of the seismograph stations. The closed squares (■) stand for heat flow values in the range $0.6 \leq \blacksquare \leq 1.2$ μcal/cm^2-sec, the closed circles (•) for values $1.2 \leq \bullet \leq 1.8$, and the star (☆) for values $1.8 \leq ☆ \leq 2.4$ μcal/cm^2-sec.

Figures 3 to 8 compare Poupinet's travel-time residuals with North's (1977) magnitude bias data for seven different regions of the world within North America, Eurasia and the South Pacific. The results for the contiguous United States (Figure 3), India (Figure 4), the Baltic Shield (Figure 5) and the Canadian Shield (Figure 6) indicate that, with few exceptions, negative travel-time residuals correlate with positive magnitude bias. That is seismically fast stations report high magnitude estimates. Slow stations, on the other hand, fairly consistently report low magnitude estimates. The negative magnitude bias (e.g., in the western United States) is attributed to the presence of zones of high attenuation in the earth's upper mantle as evidenced by the prevalence of high heat flow and positive travel-time residuals (Figure 1).

The pattern of magnitude bias and residuals for several stations located in southeast Africa (Figure 7) is opposite that for either the United States or India. Instead of being of opposite sign, the magnitude biases and mean travel-time residuals are both negative. The reason for this particular pattern is not clear at this time. Heat flow measurements in this part of Africa, which is removed from the rift system further to the north, indicate fairly low values. Molnar and Oliver (1969) found that there was efficient propagation of S_n throughout this region and, thus, by implication no anomalously high attenuating upper mantle.

Figure 8 shows travel-time residuals and magnitude bias estimates for several stations located on islands in the Tuamotu Archipelago. All of these stations, in an oceanic setting, are seismically slow and are characterized by either very small positive or negative magnitude biases. The travel time and magnitude data for all the different regions are summarized in Figure 9. In general, the data points separate into four groups. Stations on the shield areas (Indian, Baltic, Canadian and its extension into the central United States) plot

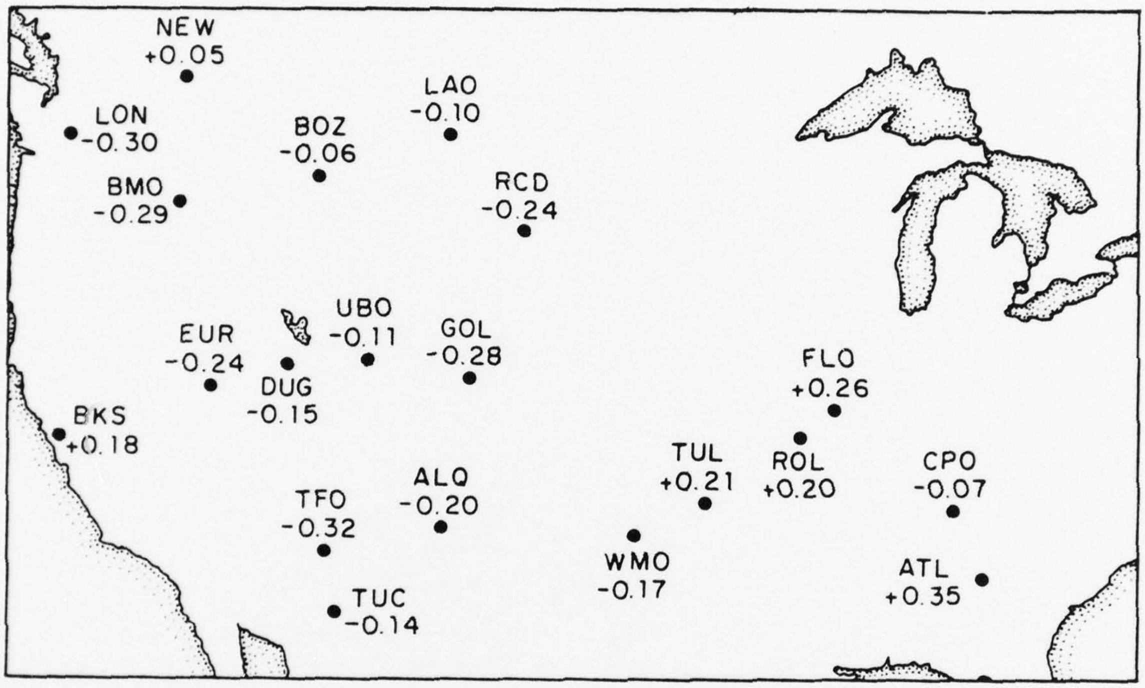

Figure 3a. Mean magnitude biases for stations in the continental USA.

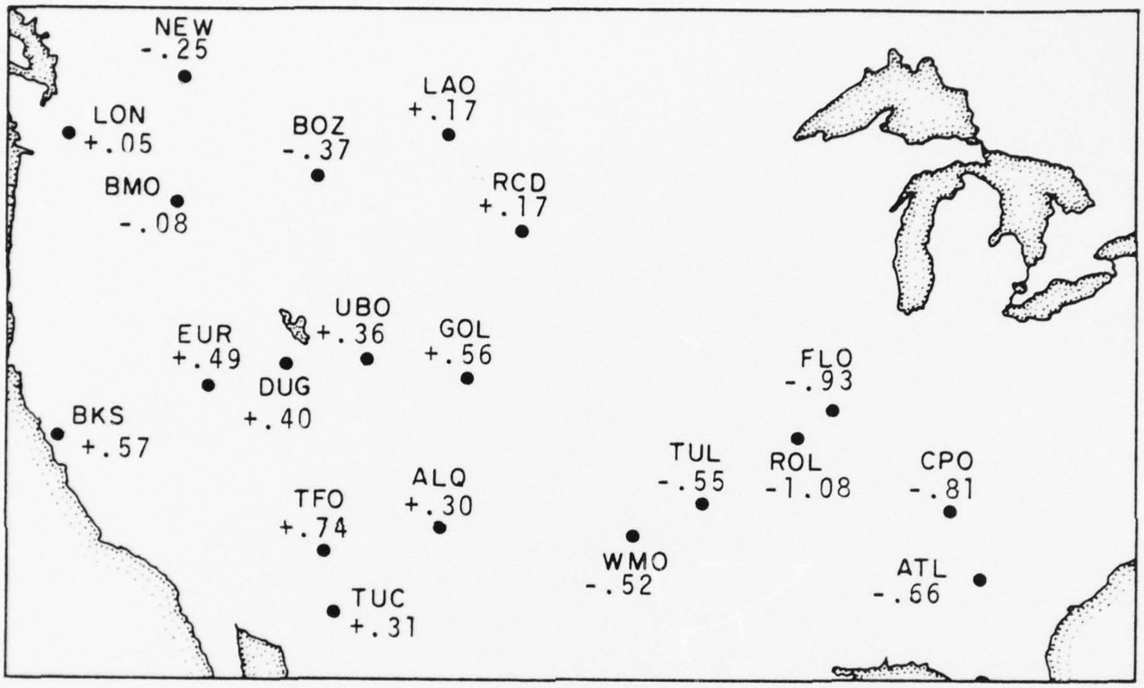

Figure 3b. Mean travel-time residuals for stations in the continental USA.

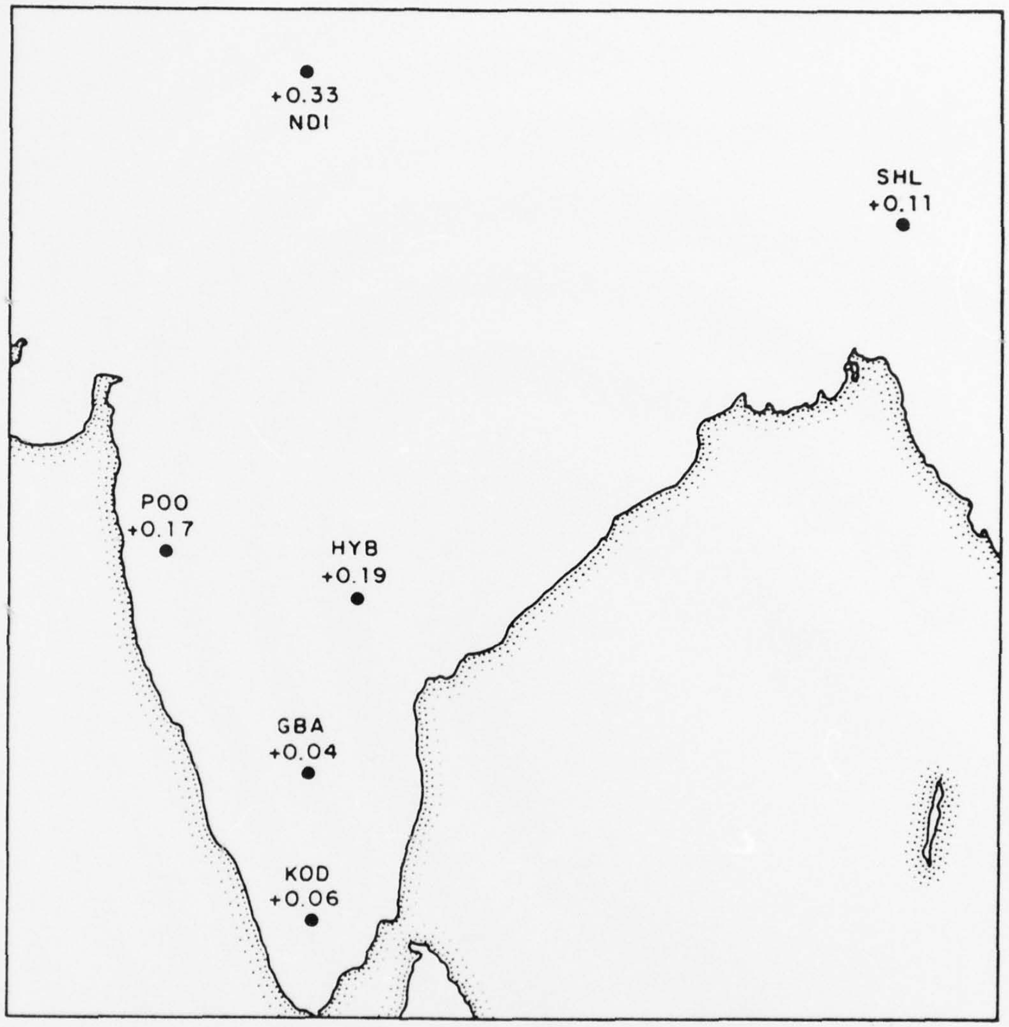

Figure 4a. Mean magnitude biases for stations in India.

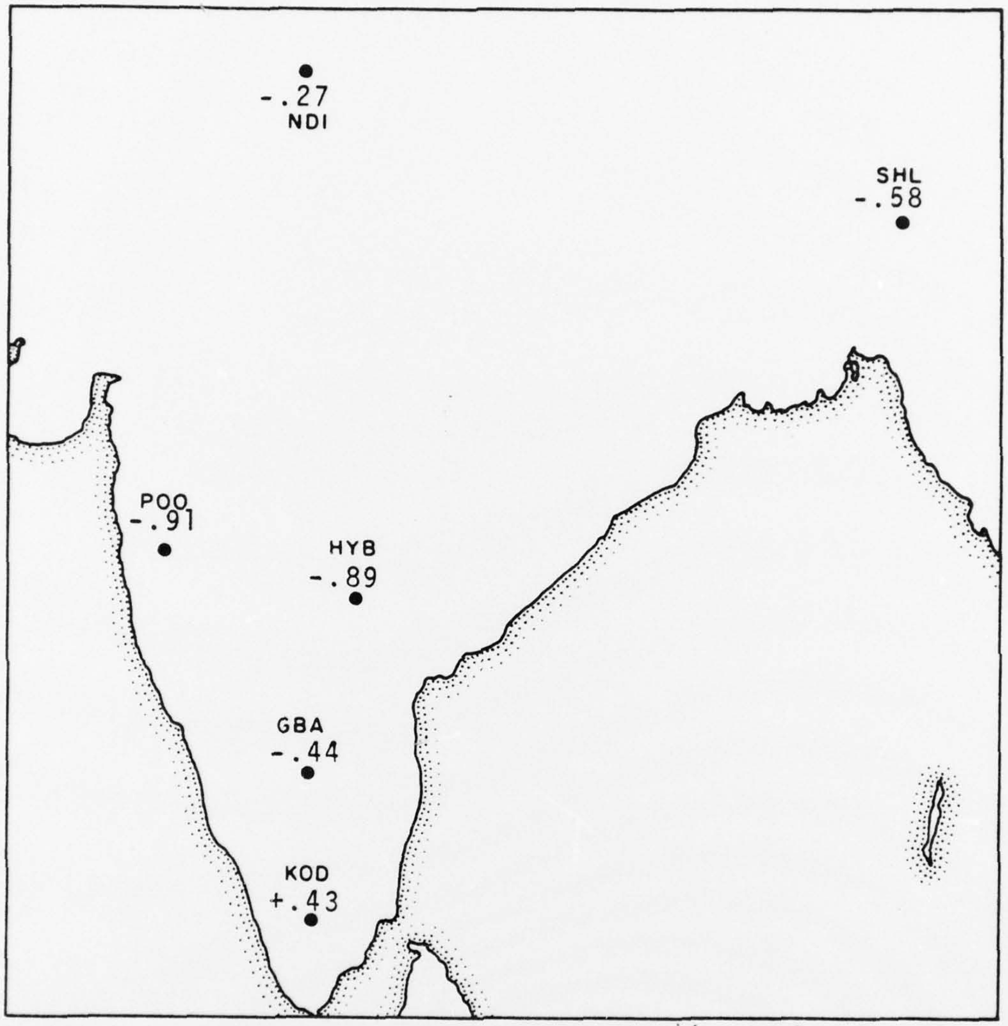

Figure 4b. Mean travel-time residuals for stations in India.

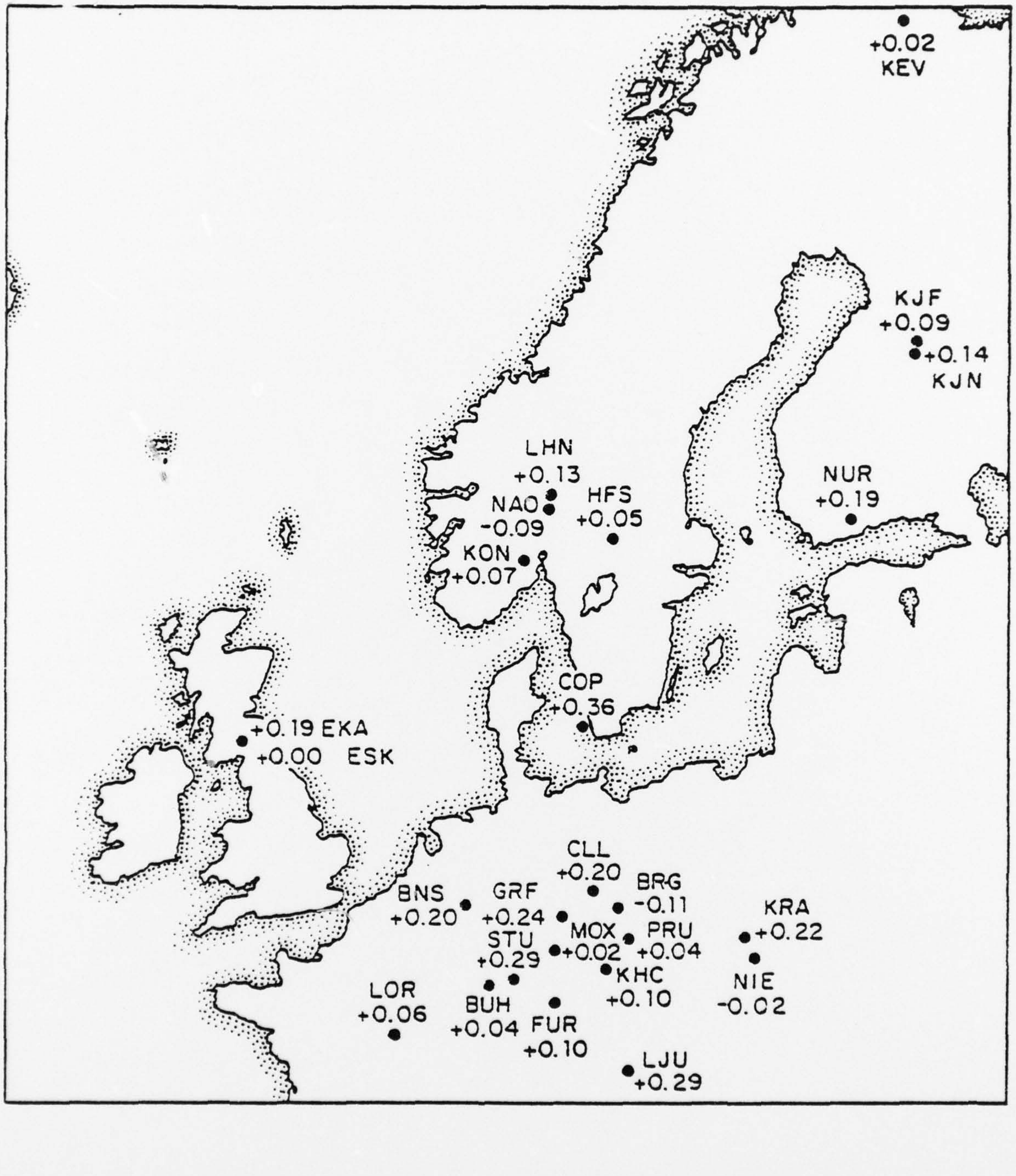

Figure 5a. Mean magnitude (m_b) biases for stations in Europe.

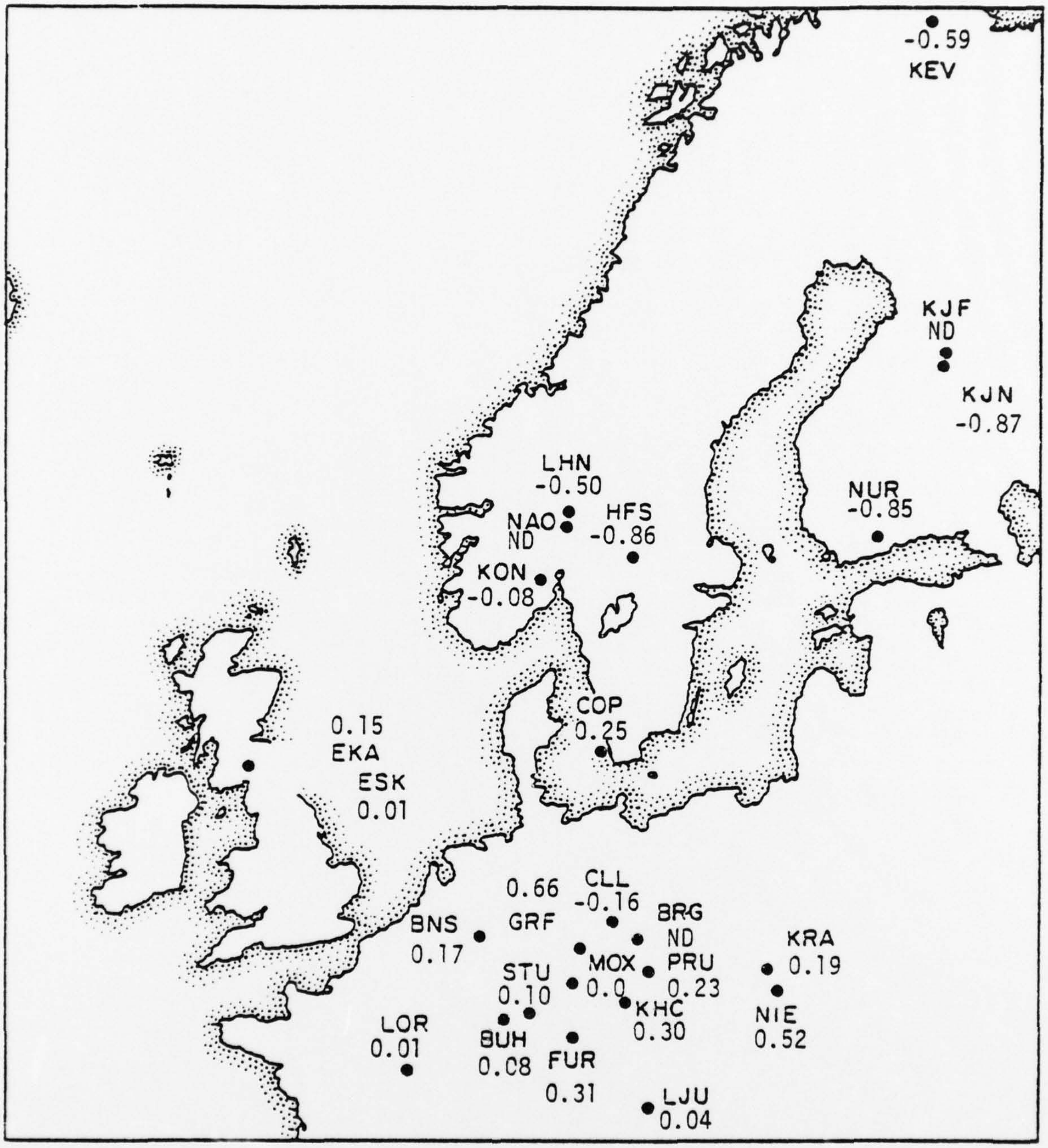

Figure 5b. Mean travel-time residuals for stations in Europe.

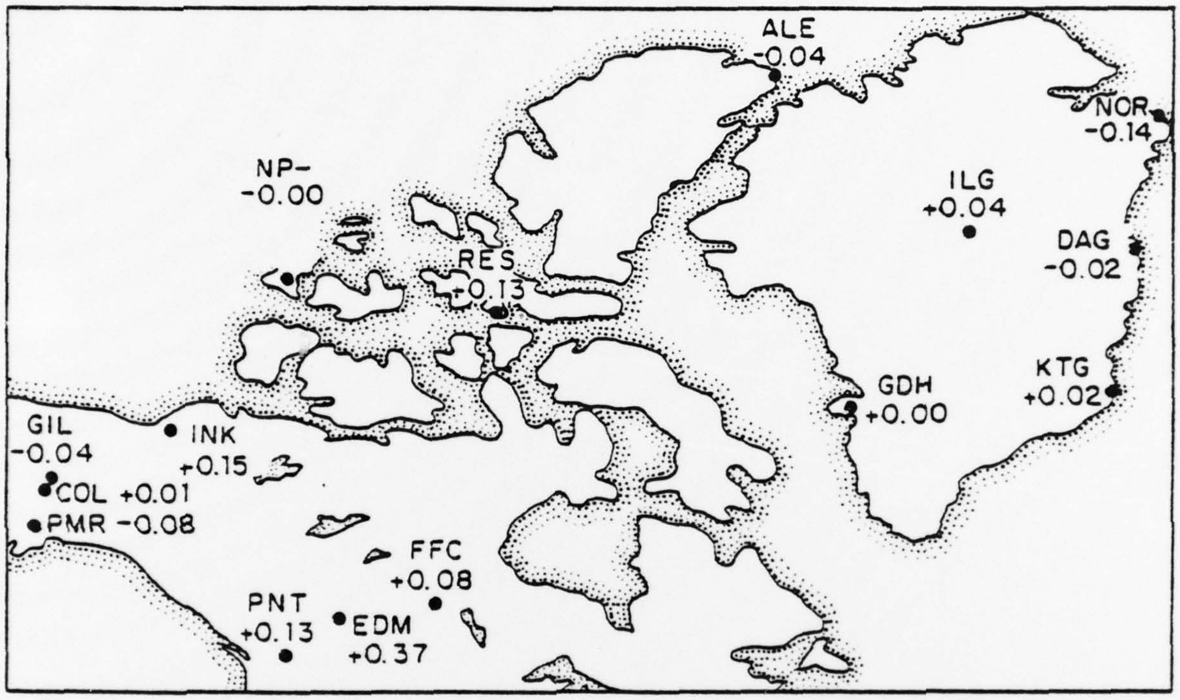

Figure 6a. Mean magnitude (m_b) biases for stations in Canada, Alaska and Greenland.

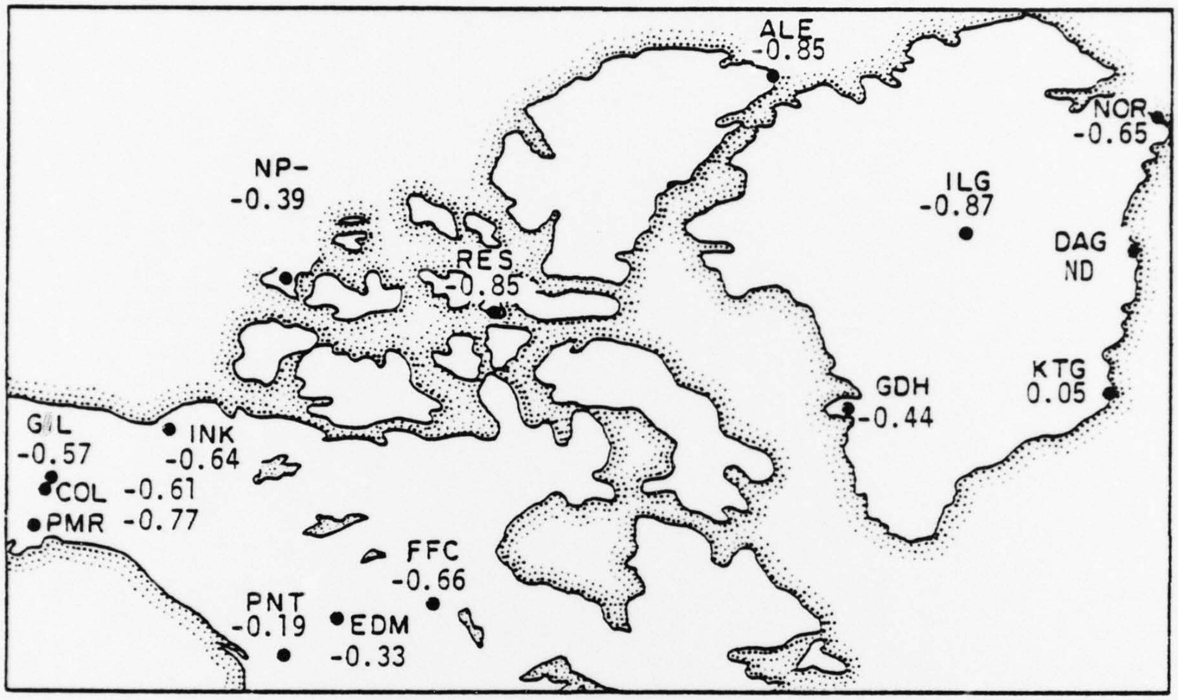

Figure 6b. Mean travel-time residuals for stations in Canada, Alaska, and Greenland.

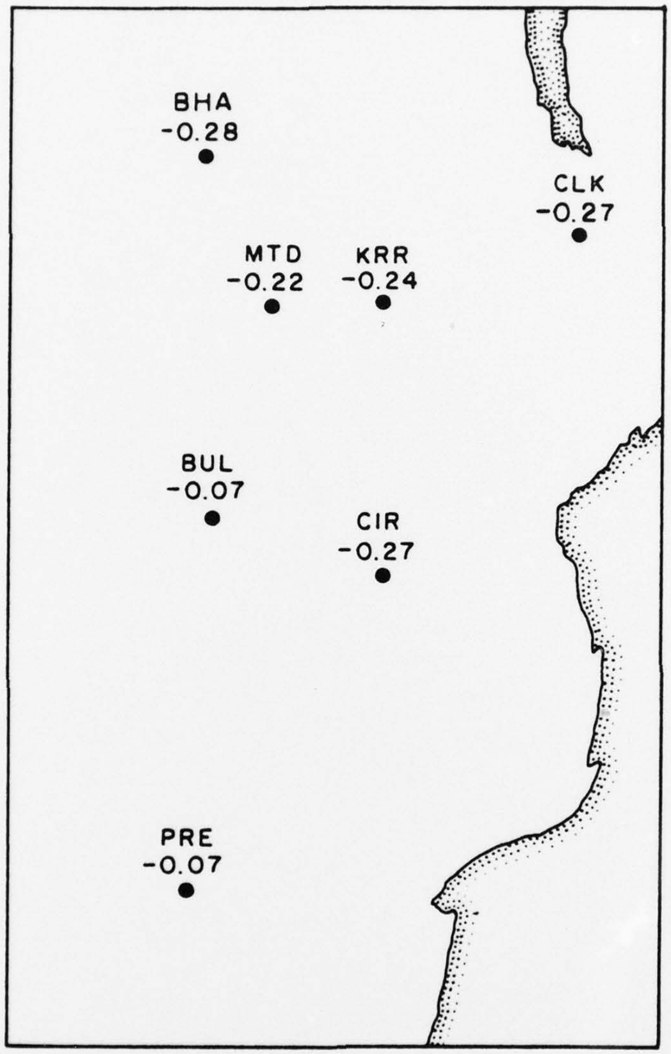

Figure 7a. Mean magnitude biases for stations in East Africa.

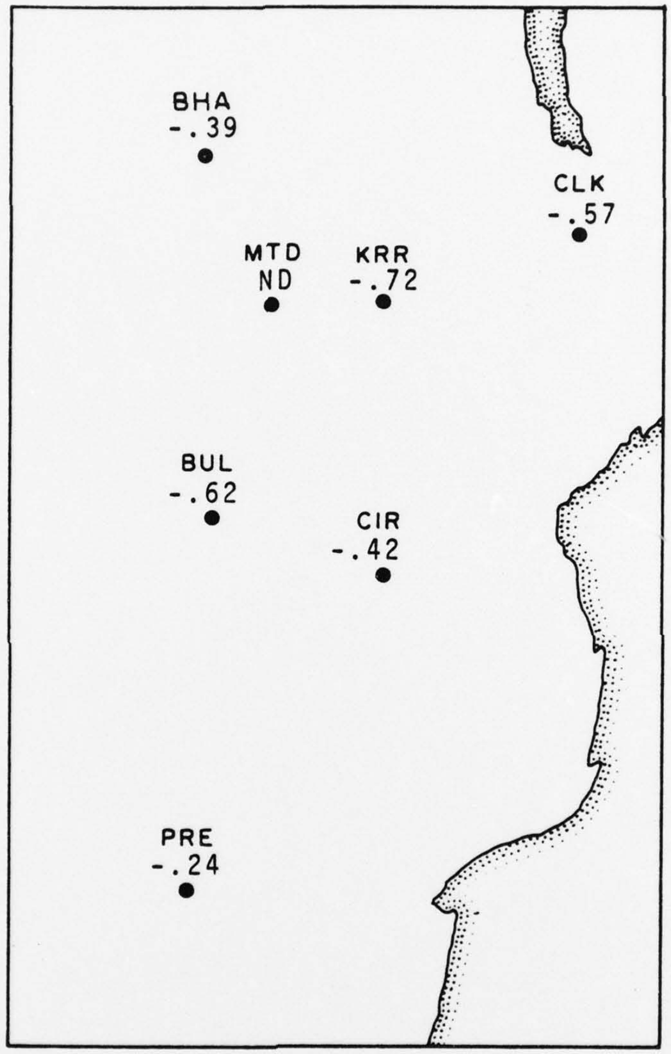

Figure 7b. Mean travel-time residuals for stations in East Africa.

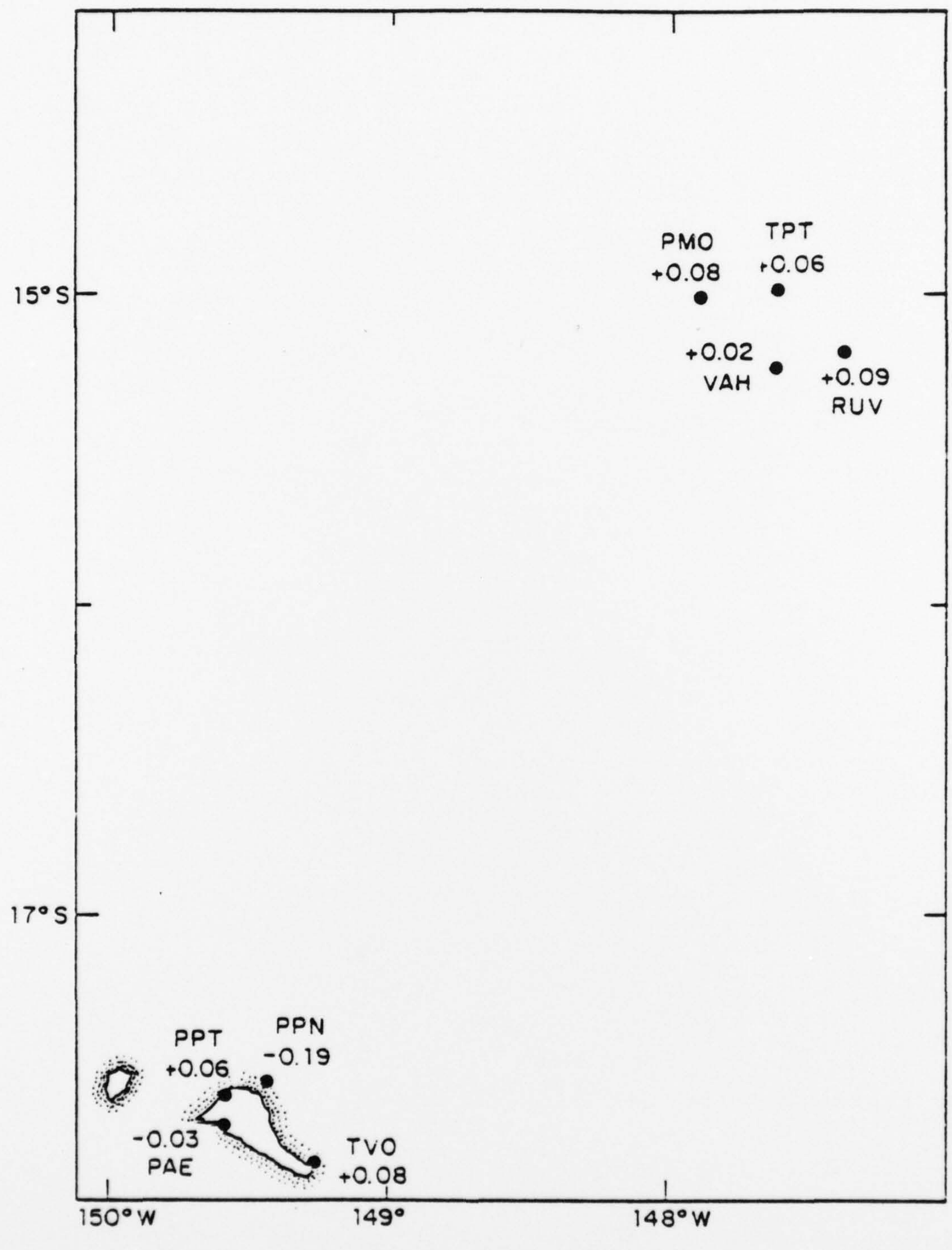

Figure 8a. Mean magnitude (m_b) biases for stations in French Polynesia.

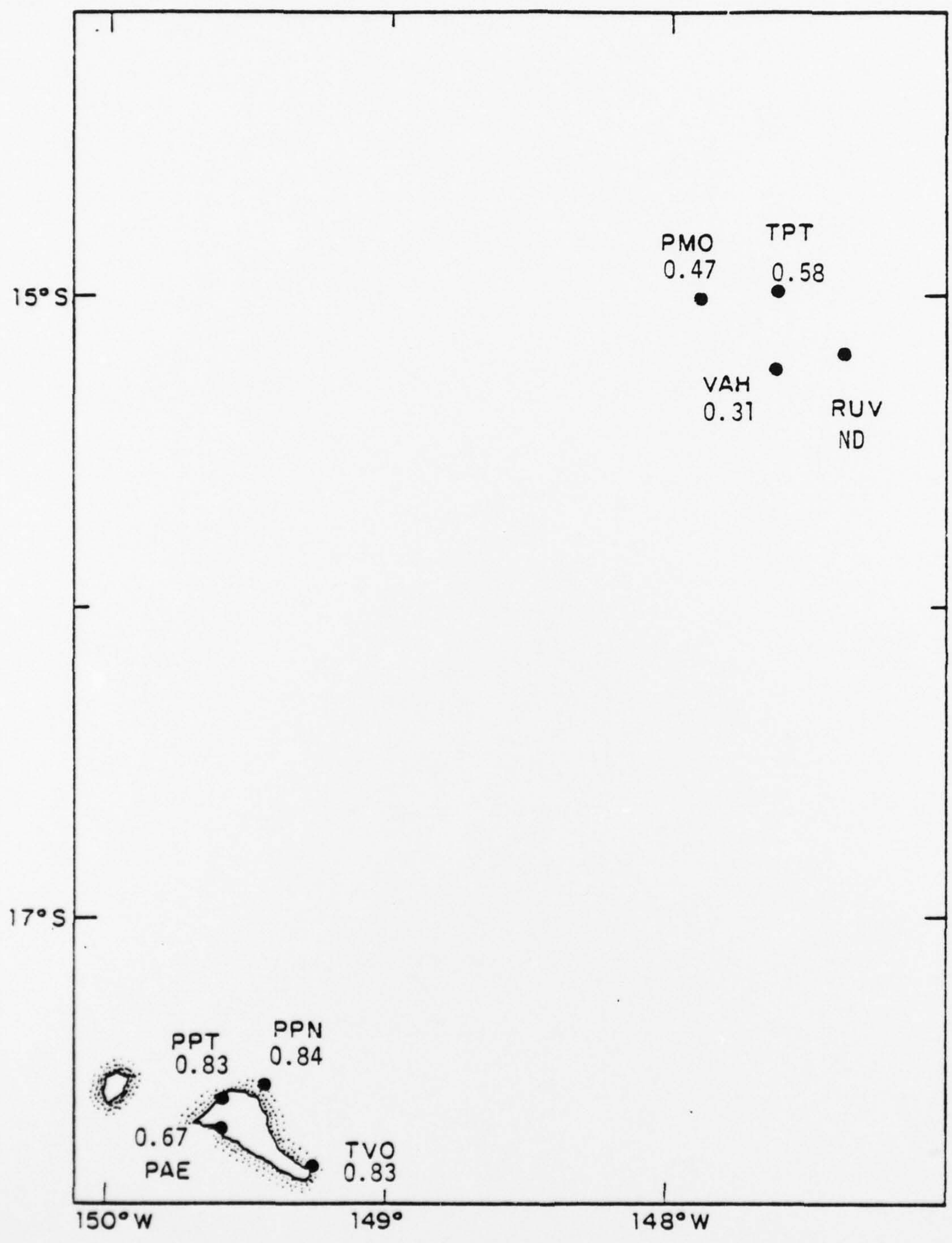

Figure 8b. Mean travel-time residuals for stations in French Polynesia. Large island at lower left is Tahiti.

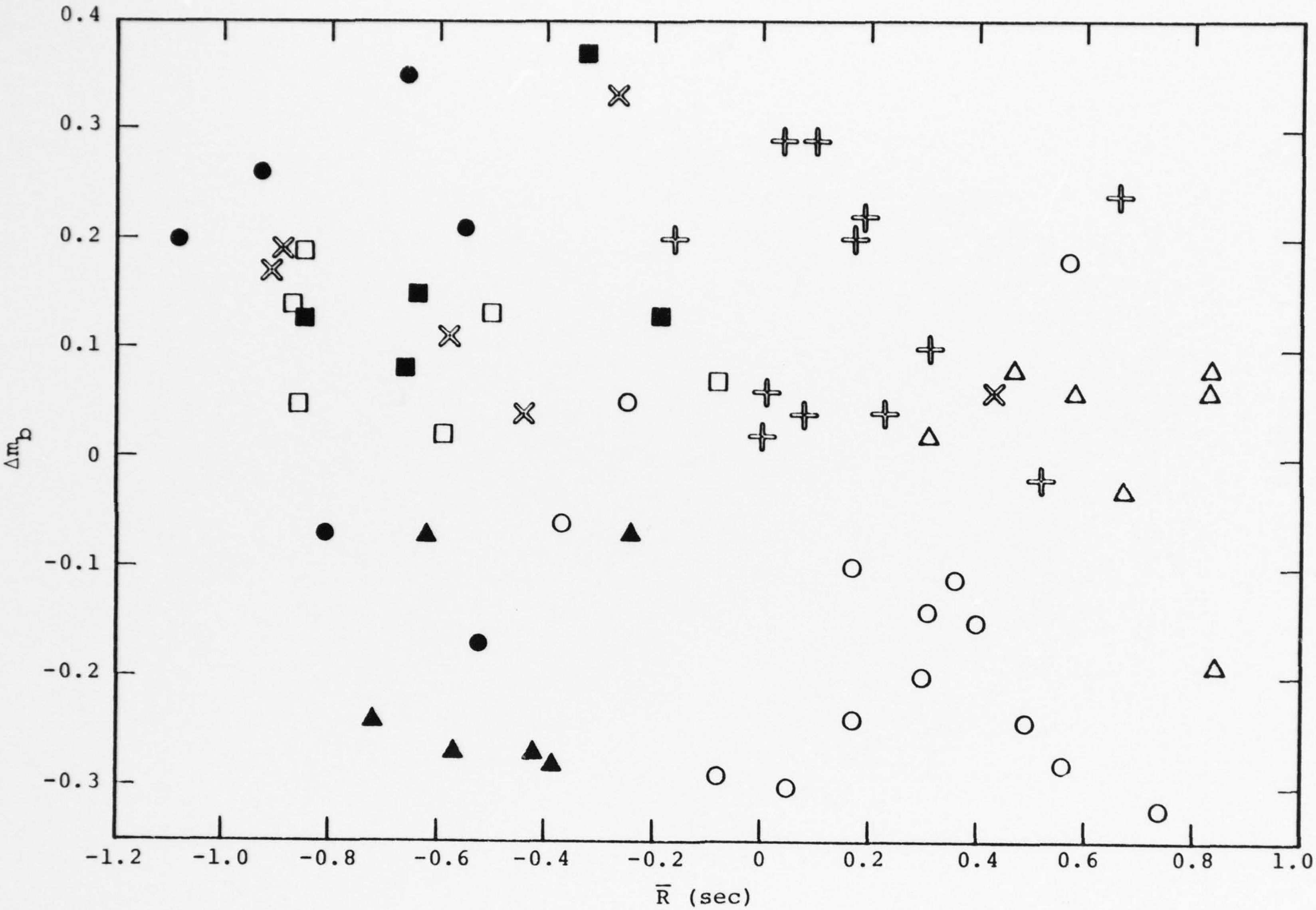

Figure 9. Magnitude bias (Δm_b) versus mean travel-time residual ($\overline{R}$) for stations grouped according to their geologic and tectonic settings. The legend for the symbols is the following: ● Eastern United States, ○ Western United States, ■ Canadian Shield, □ Baltic Shield, ✕ India, ▲ East Africa, △ French Polynesia, and ✢ Western Europe.

in the upper left-hand corner; negative travel time residuals and positive magnitude biases. Stations in the western United States, particularly the Basin and Range province, plot in the lower right-hand corner. The western European and South Pacific stations are predominantly slow and biased on the high magnitude side while the east African stations, in the lower left-hand corner, are fast and report low magnitude estimates.

While no magnitude data are available from seismic stations within the U.S.S.R., the prevalence of negative travel-time residuals, low values of heat flow, high P_n velocities and large crustal thicknesses (Ryaboy, 1977) all suggest positive magnitude biases. The residual for the station located at Semipalatinsk (-0.81 sec) is typical of stations located on either the Russian or Siberian platforms. If this region is analogous to the Interior Lowlands of the central United States, then residuals in this range could imply positive magnitude biases of 0.2 to 0.3 m_b units. However, the observed scatter in both the residual and magnitude bias data, as well as the opposite pattern observed in Africa, suggest caution in extrapolating results to Eurasia based on other regions.

REFERENCES

Bache, T. C., J. T. Cherry, D. G. Lambert, J. F. Masso and J. M. Savino (1976), "A Deterministic Methodology for Discriminating Between Earthquake and Underground Nuclear Explosions," Systems, Science and Software Final Technical Report submitted to ARPA/AFOSR, SSS-R-76-2925, July 1976.

Bache, T. C., J. F. Masso and B, F. Mason (1977), "Theoretical Body and Surface Wave Amplitudes for Twelve Numerically Simulated Cratering Explosions," Systems, Science and Software Technical Report, SSS-R-77-3119, January 1977.

Bache, T. C. and W. L. Rodi (1977), "Seismic Studies of Surface and Body Waves for Improved Yield Determination," Systems, Science and Software Quarterly Technical Report, SSS-R-78-3448, October 1977.

Cherry, J. T., T. C. Bache, W. O. Wray and J. F. Masso (1976), "Teleseismic Coupling from the Simultaneous Detonation of an Array of Nuclear Explosions," Systems, Science and Software Technical Report, SSS-R-76-2865, February 1976.

Cleary, J. and A. L. Hales (1966), "An Analysis of the Travel Times of P Waves to North American Stations, in the Distance Range 32° to 100°," Bull. Seism. Soc. Am., 56, 467-489.

de Hoop, A. T. (1958), "Representation Theorems for the Displacement in an Elastic Solid and Their Application to Elastodynamic Diffraction Theory," Doctoral Dissertation, Delft.

Lambert, D. G. and T. C. Bache (1977), "Identification of Individual Events in a Multiple Explosion from Teleseismic Short Period Body Wave Recordings," Systems, Science and Software Technical Report, SSS-R-78-3421, October 1977.

Lee, W. H. K. and S. Uyeda (1965), "Review of Heat Flow Data," in Terrestrial Heat Flow, Geophysical Monograph No. 8, Am. Geophys. Union.

REFERENCES (continued)

Molnar, P. and J. Oliver (1969), "Lateral Variations of Attention in the Upper Mantle and Discontinuities in the Lithosphere," J. Geophys. Res., 74, 2648-2682.

Ryaboy, V. Z. (1977), "Study of the Structure of the Lower Lithosphere by Explosion Seismology in the U.S.S.R.," J. Geophys., 43, 593-610.